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ATMOSPHERIC SOUND PROPAGATION NEAR THE EARTH'S SURFACE

By

RICARDO PENA

and

MARVIN DIAMOND

DA TASK 1P620901A198-02

OCTOBER 1965

U.S. ARMY
ELECTRONICS RESEARCH & DEVELOPMENT ACTIVITY
WHITE SANDS MISSILE RANGE

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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ENVIRONMENTAL SCIENCES DIRECTORATE
U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT ACTIVITY
WHITE SANDS MISSILE RANGE
NEW MEXICO

ABSTRACT

A study of sound propagation near the earth's surface under relatively calm meteorological conditions showed considerable variation in the pressure of detected waves. This variation was shown to be due to atmospheric effects between the source and detector. The accuracy of determining the elevation angle of the sound source was found to be highly dependent upon the surface temperature.

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INTRODUCTION

The detection of pressure waves generated by high-altitude explosions on previous experiments has been accompanied by considerable pressure variations between microphones of a surface array. Since the pressure waves travelled nearly vertically over paths greater than 250,000 feet the array can be considered as a single point relative to the acoustic source. Thus the portions of each wave which were detected at each microphone propagated along essentially the same path through the atmosphere. This would indicate that molecular absorption processes are the same for all parts of each wave and that absorption cannot be a cause of the observed pressure variations. However, atmospheric conditions such as temperature, wind, and turbulence near the surface are probably different at the various microphone locations of the array and might affect the wave pressure in that area.

The purpose of this report is to present the results of an experiment which was performed to study atmospheric effects on the pressure of incident acoustic waves in the air layer near the earth's surface. Information was also obtained on the accuracy with which the azimuth and elevation angle of a sound ray can be determined.

INSTRUMENTATION

The locations of the sound source and the array, which was a square 1500 feet on a side, are shown in Figure 1. The sound source consisted of an automatic device which could remotely detonate as many as thirteen 10-gauge shotgun shells at five-second intervals. The device was placed near the top of a tower, 190 feet above the surface with the barrel pointing toward the ground. Two salvos of thirteen and nine shells, respectively, were fired within a few minutes.

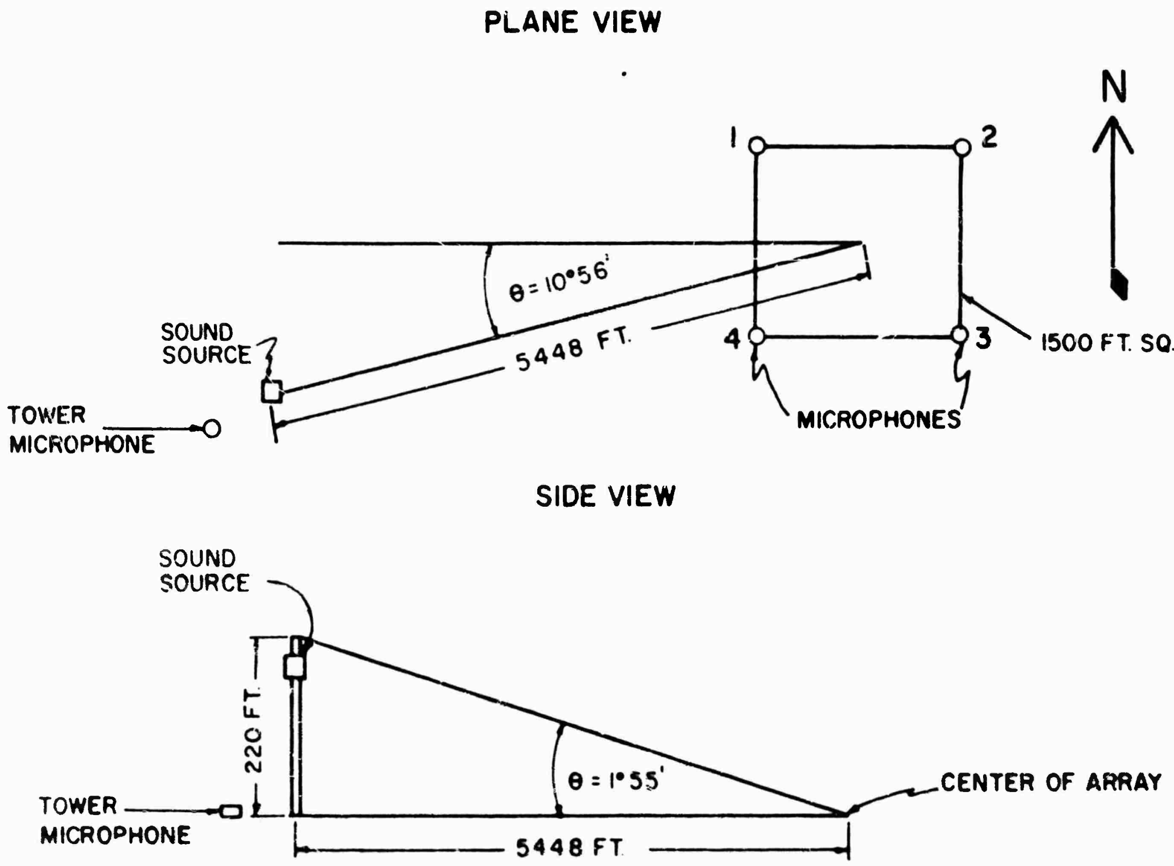
General Radio (GR) sound level meters (Model 1551C) at the base of the tower and at each corner of the array were used to monitor the generated sound. All the sound level meters were calibrated with a two-volt RMS 400-cycle source at a 120-db level prior to and after the test period.

The sound meter at the base of the tower was used to correlate variations in source intensity with variations in measured outputs of the array sound meters. If a correlation was obtained between these sensors this would establish the variations as being caused by the source.

Data were obtained between 1800 and 1900 MST on 24 February 1965. During this time surface winds were less than 2 MPH and skies were clear. The temperature was 8°C at the surface and 7°C at 1000 feet above the surface, indicating nearly isothermal conditions within this layer of air.

FIGURE 1

LOCATION OF SOUND SOURCE AND MICROPHONE ARRAY



The output of the sound meters was recorded on magnetic tape at 30 inches per second during the test period and reproduced at 1-7/8 inches per second to decrease the frequency by a factor of 16. This frequency decrease provided an accurate visual representation on the oscillograph chart of the predominant 200 cps signal detected by the sound meters. A recording of the pressure wave at the base of the tower and at an array position is shown in Figure 2.

RESULTS

PRESSURE

The mean incident pressure, standard deviation, and coefficient of variation for each position in the array and at the base of the tower are listed in Table I.

TABLE I

STATISTICS OF PRESSURE MEASUREMENTS

$n = 22$

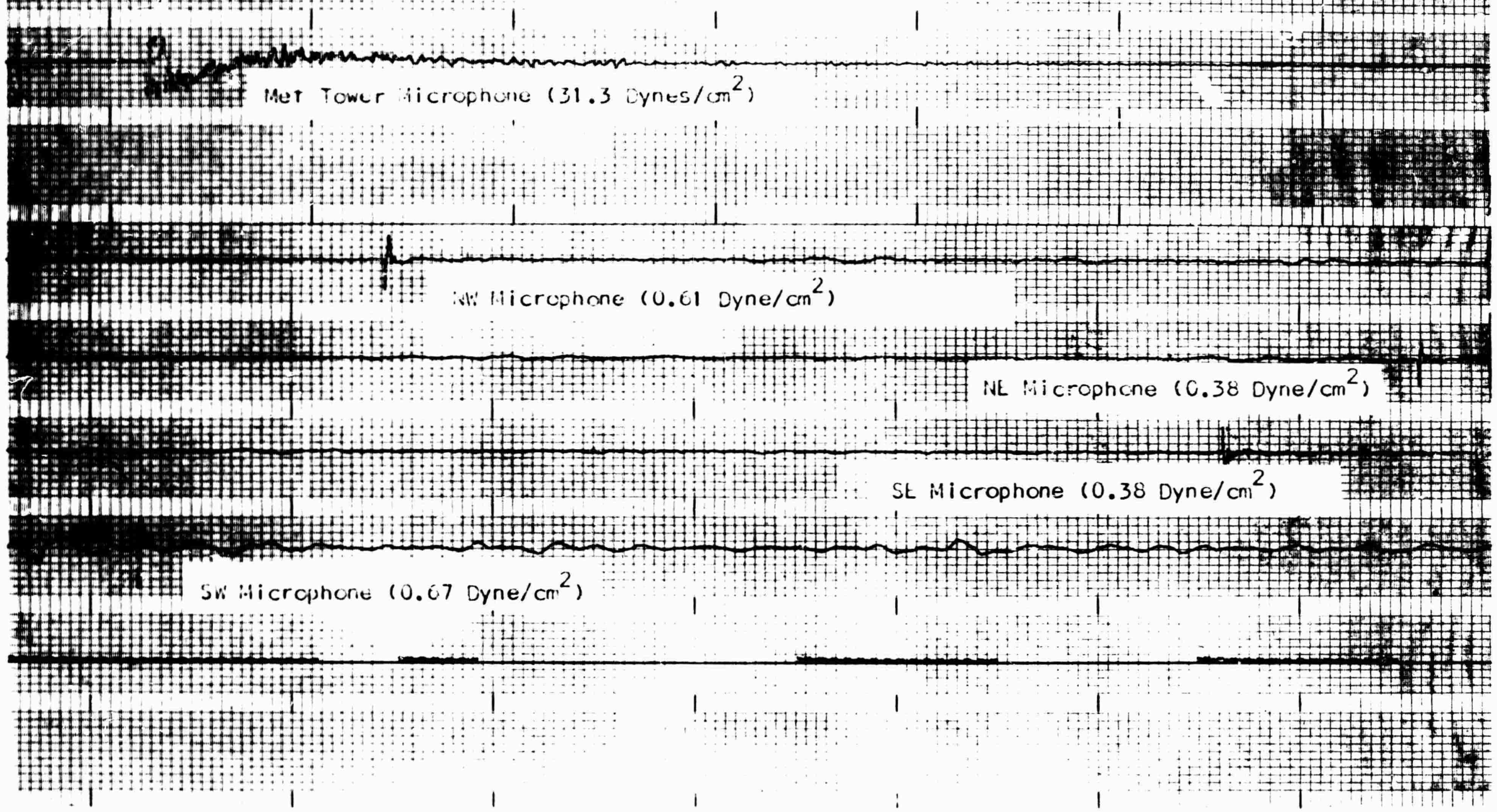
		ARRAY POSITIONS			
	TOWER	NW	NE	SE	SW
Mean Incident Peak Pressure ($\overline{X}$) dynes/cm^2	31.3	.61	.38	.38	.67
Standard Deviation (σ)	.41	.31	.08	.08	.12
Coefficient of Variation %	1.2	20	21	16	18

The higher pressure obtained at the NW and SW microphone positions would be expected since they were closer to the sound source than those at the SE and SW locations. If the decrease in amplitude between tower and array was due only to spherical divergence, the pressure at the center of the array as estimated from

$$\frac{P_{Tower}}{P_{Array}} = \frac{d_{Array}}{d_{Tower}}$$

FIGURE 2

PRESSURE WAVES



would have been about 1.2 dynes cm^{-2} which is larger than the measured values. The difference between this pressure and the ones measured at the array positions is largely due to scattering or absorption phenomena. Some energy is also lost due to the source not being isotropic with respect to the array positions.

The much larger coefficients of variation at the array positions than at the tower position indicate that the atmosphere caused pressure variations in the propagating wave; therefore, what may be described meteorologically as "calm" conditions (0-2 mph) was not the case with respect to acoustic propagation. Due to variations in temperature, humidity and wind, slight turbulence and eddies, in seemingly calm air, can produce rapid changes in the speed of sound. Such changes can result in varying focusing patterns that can cause rapid temporal fluctuations in the pressure of waves at any location. These pressure fluctuations indicate that measurements of the atmospheric parameters obtained with the usually sluggish meteorological instruments are incapable of disclosing the fine structure of the distribution of temperature, humidity, or wind.

AZIMUTH AND ELEVATION ANGLE

The determination of azimuth and elevation angle is based on the assumption that the detected sound is a plane wave front that undergoes no distortion or change of direction as the wave crosses the array. The direction of wave propagation is considered as the direction of the normal to the wave front. The possibilities of introducing an error in assuming plane wa\ instead of spherical wave propagation were investigated. It was found that the maximum possible error in wave arrival, which occurs at the SW microphone and decreases as the radius of curvature increases, is 0.035 second. Comparing the time interval ($t_4 - t_1$) of a plane and spherical wave respectively, the error reduces to 0.005 second, which when applied to the azimuth equation below will not influence the results appreciably.

In Figure 3, ABCD represents a microphone array showing microphones 1, 2, 3, 4 and W_1, W_2, W_3, W_4 are the intersections of the wave front with the horizontal plane at times t_1, t_2, t_3 and t_4, respectively. From the geometry of Figure 3 the azimuth with reference to the center of the array is obtained from

$$\tan \theta = \frac{t_4 - t_1 + t_3 - t_2}{t_4 - t_3 + t_2 - t_1}$$

Figure 4 shows the vertical plane containing the horizontal line AF. The angle (ε) which the ray path (JF) forms with the horizontal is the elevation angle of the normal to the wave front. AJ is normal to the ray path and represents the plane wave front.

FIGURE 3

GEOMETRY OF WAVE FRONT CROSSING ARRAY

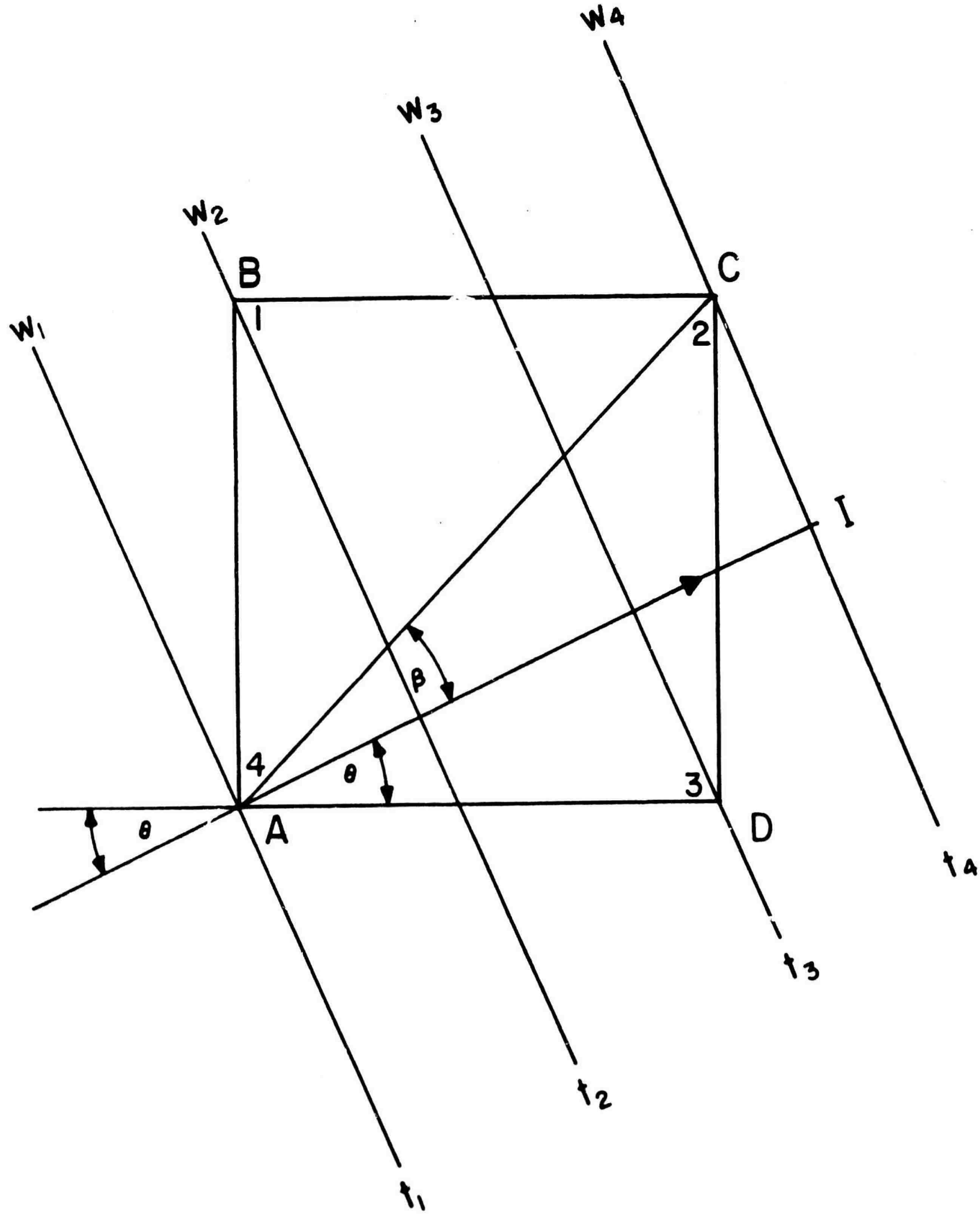
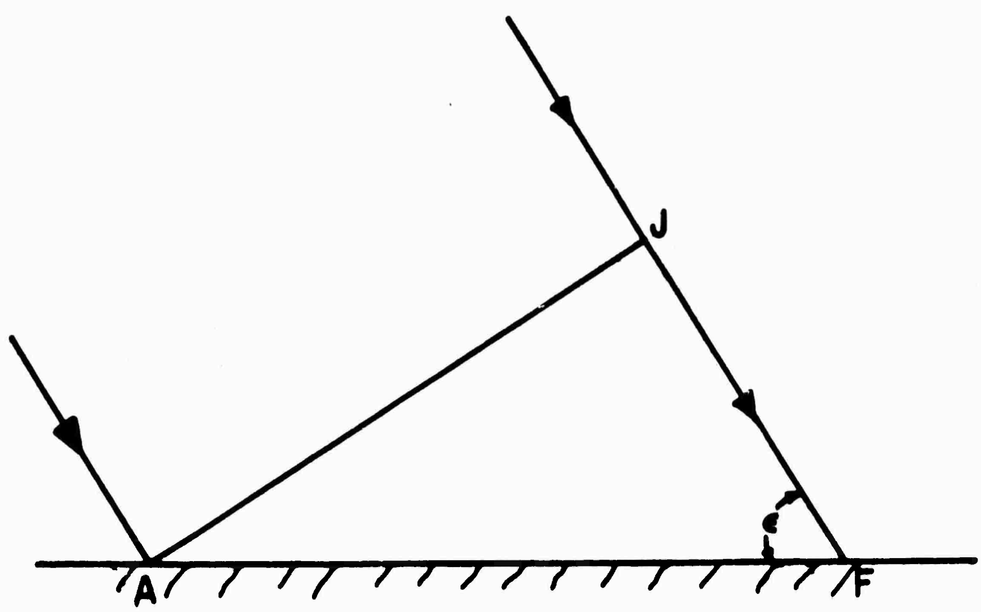


FIG. 4

GEOMETRY OF ELEVATION ANGLE COMPUTATION



The elevation angle (ε) may then be obtained from

$$\cos \varepsilon = \frac{V_s \, (t_4 - t_2)}{AC \cos \beta}$$

where V_s is the local speed of sound as obtained from local temperature and wind conditions, AC is the diagonal of the square array and β is the angle between the diagonal and the ray path (from Figure 3).

The above calculations assume that all the microphones lie in the same horizontal plane, which was true for the microphones in this experiment.

The results of the azimuth and elevation angle computations summarized in Table II show that the azimuth angle as computed from the microphone data agrees quite well with the geometric values, which indicates that the variations in pressure due to atmospheric conditions had little or no effect on the trajectory of any portion of the wave front.

Three values of elevation angles, computed from microphone data, are listed to show the effect of a one-degree error in surface temperature. The results indicate that at low elevation angles slight temperature errors can cause large errors in the computed elevation angle.

TABLE II

SUMMARY OF AZIMUTH AND ELEVATION ANGLE COMPUTATIONS

GEOMETRIC AZIMUTH	COMPUTED AZIMUTH	GEOMETRIC ELEVATION ANGLE	COMPUTED ELEVATION ANGLE
[illegible]	258°32' ± 0.13' *	1°55'	5°12' - 7°C
			3°54' - 8°C
			1°49' - 9°C

*Standard deviation

CONCLUSION

Acoustic waves travelling in the air layer near the earth's surface are greatly influenced by atmospheric conditions. It has been shown that even under relatively calm conditions, atmospheric conditions can cause variations of as much as 20 per cent in the measured pressure of sound waves. This variation was observed under assumed isothermal conditions in a surface air layer about 1000 feet thick.

Under stable meteorological conditions, the azimuth of detected sound was determined with considerable accuracy; however, the accuracy of the elevation angle was found to be highly dependent upon the surface temperature.

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